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Original article

Usefulness of modified Pulmonary Index Score (mPIS) as a quantitative tool for the evaluation of severe acute exacerbation in asthmatic children

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CIT	continuous inhalation therapy
JPGL	Japanese Pediatric Guideline for the Treatment and Management of Asthma
mPIS	modified pulmonary index score
ROC curve	receiver operating characteristic curve

ABSTRACT

Background: Acute exacerbation of asthma is divided qualitatively into mild, moderate, and severe attacks and respiratory failure. This system is, however, not suitable for estimating small changes in respiratory condition with time and for determining the efficacy of treatments, because it has a qualitative, but not quantitative nature.

Methods: To evaluate the usefulness of quantitative estimation of asthma exacerbation, modified Pulmonary Index Score (mPIS) values were measured in 87 asthmatic children (mean age, 5.0 ± 0.4 years) during hospitalization. mPIS was calculated by adding the sum of scores for 6 items (scores of 0–3 were given for each item). These consisted of heart rate, respiratory rate, accessory muscle use, inspiratory-to-expiratory flow ratio, degree of wheezing, and oxygen saturation in room air. Measurements were made at visits and at hospitalization and were then made twice a day until discharge.

Results: mPIS values were highly correlated among raters. mPIS values at visits were 9.1 ± 0.1 and 12.6 ± 0.4 in subjects with moderate and severe attacks, respectively ($p < 0.001$). mPIS values of subjects requiring continuous inhalation therapy (CIT) with isoproterenol in addition to systemic steroids were significantly higher than the values of those without CIT (12.0 ± 0.5 and 9.3 ± 0.2, respectively, $p < 0.001$). A score of 10 was suggested to be the optimal cutoff for distinguishing between subjects requiring and not requiring CIT, from the perspectives of both sensitivity and specificity. mPIS at hospitalization correlated well with the period until discharge, suggesting that this score was a useful predictor for the clinical course after hospitalization.

Conclusions: mPIS could be a useful tool for several aspects during acute asthma attacks, including the determination of a treatment plan, and prediction of the period of hospitalization in admitted patients, although prospective studies would be required to establish our hypothesis.

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Introduction

In Japan, the degree of severity of acute attacks of childhood asthma is usually evaluated based on the Japanese Pediatric Guideline for the Treatment and Management of Asthma 2012 (JPGL 2012).[1] Severity is divided qualitatively into mild, moderate, and severe attacks and respiratory failure depending on the respiratory status, the patient's quality of life, and other aspects. This system is, however, sometimes difficult to use because of the complexity of the evaluation items and thus yields discrepancies between evaluators. In addition, it is not suitable for estimating small changes in respiratory condition with time and for determining the efficacy of treatments, because it has a qualitative, but not quantitative nature.

Modified Pulmonary Index Score (mPIS) is a quantitative method of evaluating respiratory conditions in asthmatic subjects that was proposed by Carroll et al., in 2005.[2] This method consists of 6 evaluation items, which are important for the assessment of

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dyspnea and are relatively easy to assess in clinical practice, namely heart rate, respiratory rate, accessory muscle use, inspiratory-to-expiratory flow ratio, degree of wheezing, and oxygen saturation in room air.

JPGL 2012 recommend that hospitalization should be considered in patients with acute attacks with moderate or higher severity requiring systemic steroids. Continuous inhalation therapy (CIT) with isoproterenol is recommended for hospitalized patients with persistent dyspnea, in addition to systemic steroids.[1,3–5]

In the present study, we investigated the clinical usefulness of evaluating mPIS for severe exacerbation in asthmatic children requiring hospitalization. Thus, we measured the mPIS of hospitalized children after a hospital visit for acute exacerbation. For this purpose, we examined the validity of this method among different raters. In particular, we also evaluated clinical usefulness as a treatment plan indicator and a clinical course predictor after hospitalization.

Methods

Study subjects

Subjects of the present study were 87 asthmatic children (57 males and 30 females) who visited Saitama Medical University Hospital for acute exacerbation during the period from July 2010 to December 2012.

All subjects were hospitalized despite treatment in an emergency room. The mean age was 5.0 years old (ranging from 0 to 15 years). Actual severity (severity considering current therapies administered)[1] in these subjects had been intermittent ($n = 45$), mild persistent ($n = 16$), moderate persistent ($n = 11$) and severe persistent ($n = 4$). In 11 patients, this was the first episode of asthma attack. The asthma attack severity was estimated by the treated physician as moderate and severe according to the criteria of JPGL 2012 in 59 (67%) and 28 (33%) subjects, respectively. Physicians in the emergency room treated each patient according to JPGL 2012 for acute attacks. Patients without obvious improvement in asthmatic symptoms despite treatment with inhaled beta 2 agonists and some patients without obvious improvement in asthmatic symptoms despite treatment with systemic steroids were hospitalized. After hospitalization, all hospitalized patients received systemic steroids. In addition, in some hospitalized patients requiring further treatments in addition to repeated inhalation of beta 2 agonists because of persistence or worsening of dyspnea, CIT with isoproterenol was initiated (CIT group, $n = 29$, 33%) according to the criteria of JPGL 2012. The decision of initiation was made based on the judgment of each physician in charge.

Patients without CIT (non-CIT group, $n = 58$) inhaled short-acting beta 2 agonists 4 times a day, in addition to systemic steroids. Patients with obvious infiltration on chest radiography or those complicated with other thoracic or cardiovascular diseases such as tracheomalacia or congenital heart diseases were excluded from the present study (Table 1).

This study was approved by the Ethics Committee of Saitama Medical University (approval number, 13-075-1).

Measurement of mPIS

Measurement of mPIS was performed according to a previous report.[2] In brief, mPIS was calculated by adding the sum of scores for 6 items (scores of 0–3 were given for each item). Thus, mPIS ranged from 0 to 18, with the latter score being the most severe condition. These 6 items consisted of heart rate, respiratory rate, accessory muscle use, inspiratory-to-expiratory flow ratio, degree of wheezing, and oxygen saturation in room air (Table 2).

Table 1
Profiles of study subjects ($N = 87$).

Study period	July 1, 2010–December 31, 2012
Age (mean±1SD)	0–15 (5.0±3.2) yrs
Sex	
Male	57 (66%)
Female	30 (34%)
Classification of asthma severity by JPGL 2012	
Intermittent	45 (52%)
Mild persistent	16 (18%)
Moderate persistent	11 (12%)
Severe persistent	4 (4%)
First attack	11 (14%)
Severity of asthma exacerbation on visits	
Mild	0 (0%)
Moderate	59 (67%)
Severe	28 (33%)
Respiratory failure	0 (0%)
Treatment after hospitalization	
Systemic hydrocortisone without CIT	58 (67%)
Systemic hydrocortisone with CIT	29 (33%)

CIT, continuous inhalation therapy with isoproterenol.

Scores were determined for measurements in room air and, when oxygen was used, they were measured after discontinuation of oxygen for more than 2 min. In the case that SpO_2 decreased below 90% after discontinuation of oxygen, the score was defined as 3 without waiting more than 2 min, and oxygenation was reinitiated.

Measurements of mPIS were performed by a pediatrician at Saitama Medical University Hospital ($n = 15$) or a nurse in the pediatric ward of Saitama Medical University Hospital ($n = 33$). Before measuring mPIS, all relevant staff had been trained on how to evaluate mPIS; training involved watching a DVD prepared by the study titled, “A comparison of continuous inhalation of salbutamol and continuous inhalation of isoproterenol for severe pediatric bronchial asthma: A multicenter, double-blind, randomized study” (grant support from the Ministry of Health, Labour and Welfare).[6] The mPIS of study subjects was principally measured at rest.

Measurements of mPIS at visits and at the time of hospitalization (mPIS at hospitalization) were calculated by the physician who examined each patient in the emergency room and by nurses in the pediatric ward twice a day after hospitalization until discharge. mPIS on discharge was defined as mPIS on the day of discharge.

Relationships of mPIS among raters

To examine the relationships of mPIS among raters, 4 medical staff (2 physicians and 2 nurses) measured the mPIS of the same randomly selected patients at the same time during hospitalization.

These patients included 7 boys and 4 girls with the mean ages of 6.0 ± 1.2 years old (2–13 years old).

The details of the raters were as follows: Physicians 1 and 2 were working as pediatricians for 6 years and 2 years, respectively, with experience of measuring mPIS over 1 year and less than 1 year, respectively. Nurses 1 and 2 were working for 6 years and 2 years, respectively, with experience of measuring mPIS for over 1 year and less than 1 year, respectively. These 4 raters went into the bedroom of each selected patient and began measuring mPIS at the same time. In all selected patients, the time was within 5 min in all raters measuring mPIS.

mPIS and qualitative evaluation of asthma attack severity

At each visit, the physician who examined the study subject in the emergency room measured mPIS in addition to qualitatively

Table 2
The modified Pulmonary Index Score.

	Heart rate/min		Respiratory rate/min		Accessory muscle use	Inhalation-exhalation ratio	Wheezing	Oxygen saturation % (room air)
	<3 years old	≧3 years old	<6 years old	≧6 years old				
0	<120	<100	≦30	≦20	None	2:1	None	96≦
1	120–140	100–120	31–45	21–35	Mild	1:1	End expiratory	93–95
2	141–160	121–140	46–60	36–50	Moderate	1:2	Inspiratory and expiratory wheeze, good aeration	90–92
3	160<	140<	60<	50<	Severe	1:3	Inspiratory and expiratory wheeze, decreased aeration	<90

evaluating the severity as mild, moderate, and severe attacks or respiratory failure according to JPGL 2012. The relationships between these items were then analyzed.

mPIS at hospitalization and the duration of hospitalization

The correlation of mPIS at hospitalization with the duration of hospitalization was evaluated in all study subjects.

Comparison between subjects with and without CIT with isoproterenol

mPIS at hospitalization between subjects with and without CIT with isoproterenol was compared. A receiver operating characteristic curve (ROC curve) for these 2 groups was made to find the cutoff value for the indication of CIT. The relationship between mPIS at hospitalization and the period of hospitalization was examined among subjects with CIT.

Statistical analysis

A Mann–Whitney *U* test was used for the comparison between groups, and Spearman's rank correlation was used for the analysis of correlations between groups. Data are presented as means ± SEM. *P* values of <0.05 were considered to be significant.

Results

Relationship of mPIS among raters

The degree of relatedness between raters in terms of mPIS is shown in Fig. 1. The correlation was high irrespective of rater's working experience, with correlation coefficients (rs) ranging from 0.92 to 0.96 ($p < 0.01$ for all examinations).

Correlation of mPIS with qualitative evaluation of asthma attack severity

mPIS values at visits in patients with moderate and severe attacks were 9.1 ± 0.1 (5–12) and 12.6 ± 0.4 (9–17), respectively. There was a significant difference between groups ($p < 0.001$). However, it was found that several patients with severe attacks showed lower mPIS values compared with the values of those with moderate attacks (Fig. 2).

Changes in mPIS after visiting the emergency room

The mean mPIS values of all study subjects after visiting the emergency room were 10.2 ± 0.3, 9.0 ± 0.3, and 1.9 ± 0.2 at the time of visits, at hospitalization, and on discharge, respectively (Fig. 3). The mean duration of hospitalization was 5.4 ± 0.2 days (2–13 days), and a significant correlation was found between mPIS at hospitalization and the duration of hospitalization ($rs = 0.34$, $p < 0.01$, Fig. 4)

Comparison between subjects with and without CIT with isoproterenol

mPIS values at hospitalization were 12.0 ± 0.5 and 9.3 ± 0.2 in subjects with and without CIT, respectively. A significantly higher value was observed in subjects with CIT than in those without CIT ($p < 0.001$). However, it was found that several patients with CIT showed lower mPIS values compared with the values shown by those without CIT (Fig. 5).

An ROC curve for the indication of CIT according to mPIS values of subjects with and without CIT is shown in Fig. 6. A value of 10 was demonstrated to be the optimal cutoff for distinguishing between patients requiring CIT and those not requiring it, from the perspectives of both sensitivity (72%) and specificity (78%).

The mean hospitalization period in subjects with CIT was 6.3 ± 0.4 days (3–13 days), and mPIS values at hospitalization and hospitalization period correlated well in these subjects ($rs = 0.53$, $p < 0.01$) (Fig. 4).

Discussion

In the present study, we showed that mPIS value was highly correlated among raters. This method could be a useful tool for several aspects during acute asthma attacks, including the determination of a treatment plan, and prediction of the period of hospitalization in admitted patients, although our study design was retrospective but not prospective.

In JPGL 2012, asthma attack severity is qualitatively estimated as mild, moderate, and severe attacks and respiratory failure based on conditions such as respiration status, feeling of dyspnea, quality of life, and the degree of unconsciousness, part of which are subjective rather than objective. In addition, this method is not suitable for the evaluation of changes in symptoms or for evaluating treatment effects because of its qualitative nature. For these reasons, we wanted to examine the usefulness of the quantitative evaluation of asthma attack severity by employing mPIS. Thus, we measured changes in mPIS with time after visiting an ER and then after hospitalization.

Carroll et al.[2] modified the pulmonary index reported by Becker et al.[7] as mPIS by adding 2 scoring items, namely heart rate and SpO_2 at room temperature, and by dividing the method of heart rate and respiratory rate scoring depending on which of 2 age groups the patient belong to. They compared mPIS measured by physicians, nurses, and respiratory therapists in 30 hospitalized patients with asthma attacks. As a result, they found high correlations of mPIS among these 3 professions. Several scoring systems have been previously proposed.[8–10] Among them, we have adopted mPIS in the present study because of the reasons below. First, as mentioned above, mPIS has been shown to be highly correlated among raters. Secondly, we could train ourselves using an educational DVD[6] to learn how we could perform evaluations for mPIS. In the present study, similar to Carroll et al.,[2] we also wanted to examine the correlation of mPIS among raters. As a result,

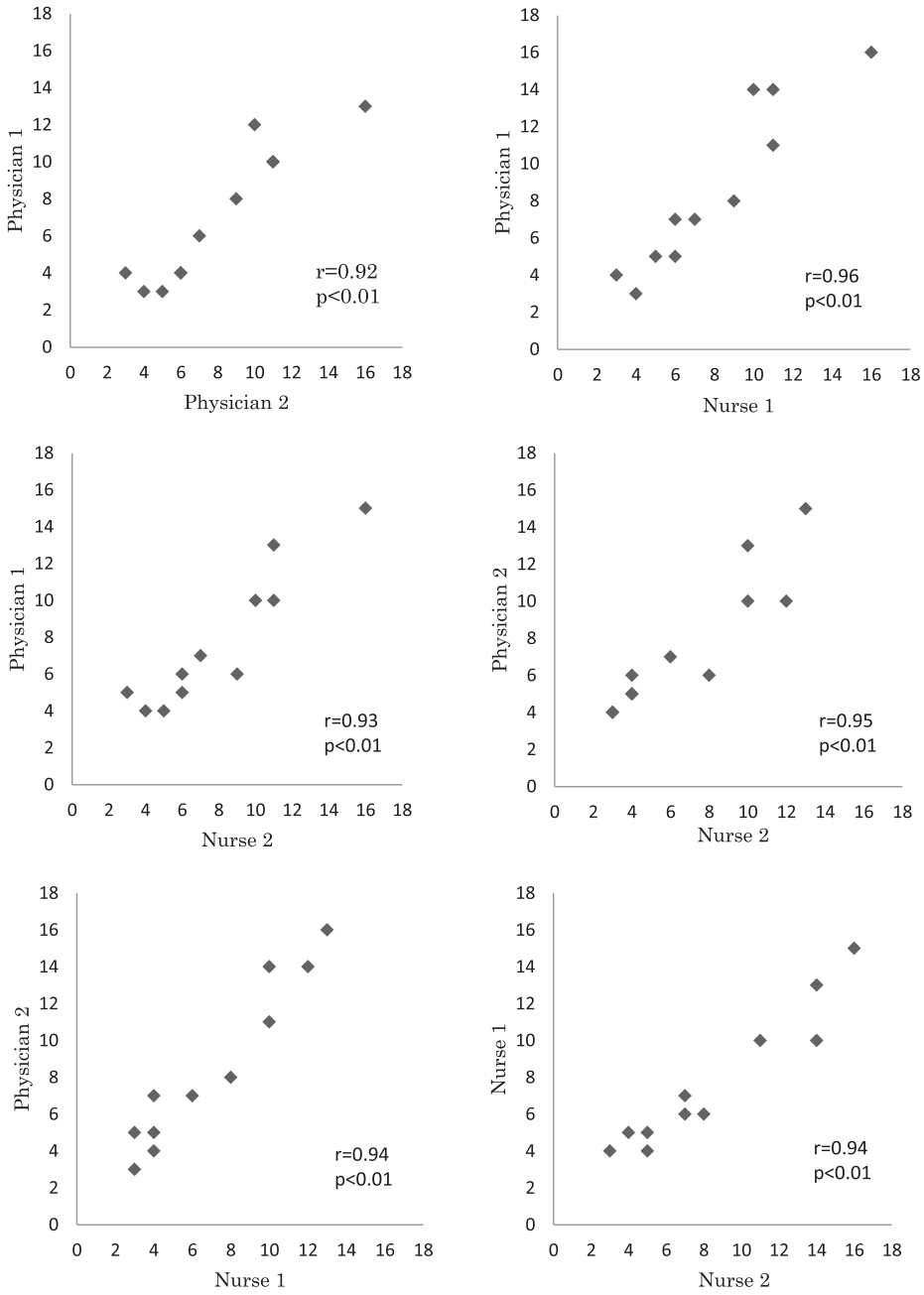

Fig. 1. Relationship of mPIS among 4 different observers. mPIS of 11 study subjects was measured by 4 observers (Physicians 1 and 2 and Nurses 1 and 2) at the same time points. Physician 1 and Nurse 1 had over 1 year of experience in measuring mPIS, while Physician 2 and Nurse 2 had less than 1 year of experience.

correlations among 4 raters, of whom 2 were physicians and 2 were nurses, were very high irrespective of their professions or their working experience, supporting the results of the report by Carroll et al.[2] Buyuktiryaki et al.[11] showed that mPIS might be useful for the determination of admission for asthma attacks by making ROC curves, although they did not evaluate the correlation among raters. Our present study showed the possibility that mPIS might be also useful for the determination of a treatment plan, including the indication of CIT, and prediction of the period of hospitalization in admitted patients.

In the present study, mPIS of subjects with severe attacks was significantly higher than that of those with moderate severity. However, several patients were judged as having severe attacks, even though their mPIS values were relatively low. On the contrary, some were judged as having moderate attacks despite high mPIS values. A possible reason for the divergence between mPIS and the estimate of asthma attack severity is that the latter was likely to be affected by the strength of apparent symptoms. Namely, there was a tendency that the severity was estimated to be severe when a symptom that might suggest dyspnea was apparent. For example, there were 17 patients with an mPIS of 12 in the present study. Among these, 7 and 10 subjects were judged as having moderate and severe attacks, respectively. When noticing the degree of wheezing in mPIS, an item that might strongly suggest dyspnea, none of the 7 patients with moderate attack were given scores of 3, the maximum for this item, while this was the case for 8 of 10 patients with severe attacks. On the other hand, 5 patients were judged as having severe attacks despite low mPIS values ($\leq$10). In

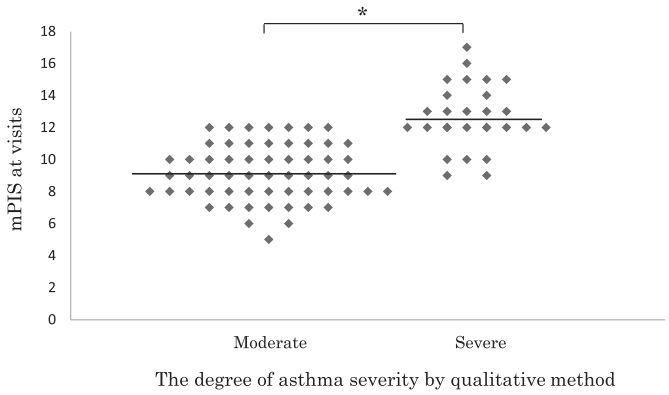

Fig. 2. Comparison of mPIS at visits between subjects with moderate and severe severities, estimated by a qualitative method. Both parameters were measured at the same time by the same physicians. mPIS was significantly higher in severe subjects (12.6 ± 0.6) than in moderate subjects (9.1 ± 0.1). $^{*}p < 0.001$.

these subjects, it was possible that the severity had been overestimated because of complications such as severe rhinitis or bronchitis.

An analysis of the ROC curve found that an mPIS value of 10 was the optimal cutoff for the indication of CIT, from perspectives of both sensitivity and specificity. According to the criteria of JPGL 2012, we performed CIT in selected patients requiring further treatments in addition to repeated inhalation of beta 2 agonists because of persistence or worsening of dyspnea. The decision was made by each physician in charge. However, some patients in the present study with mPIS values of 10 or more were found to have not undergone CIT. On the contrary, some subjects underwent CIT even though their mPIS values were less than 9. A possible reason for this discrepancy is that CIT tended to be applied to cases in which apparent symptoms were more severe. For example, we have examined study subjects with mPIS values of 9–11, a range in which there were both cases with and without CIT. As a result, CIT was applied to 18 cases (69%) among 26 subjects whose mPIS was scored as 3, the most severe score, for at least 1 item. In contrast, only 5 cases (33%) among 15 patients who were scored from 1 to 2 for all mPIS items underwent CIT. A prospective study might be required for better understanding of the optimal cutoff point. Nevertheless, this study suggested that adopting quantitative methods such as mPIS, in addition to the conventional qualitative

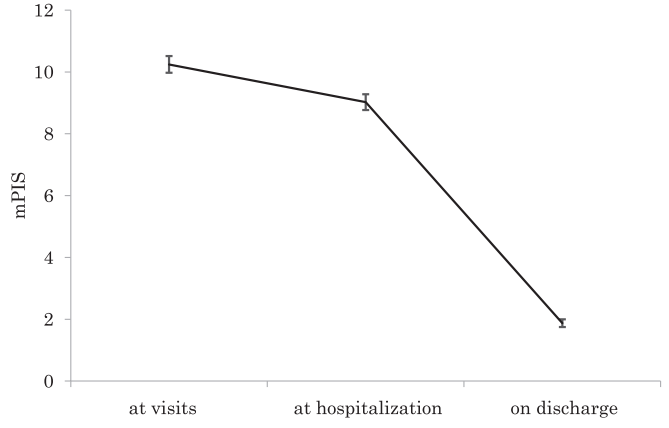

Fig. 3. Mean mPIS values of all study subjects at each time point during hospitalization. The mean mPIS values at visits, at hospitalization, and on discharge were 10.2 ± 0.3, 9.0 ± 0.3, and 1.9 ± 0.2, respectively.

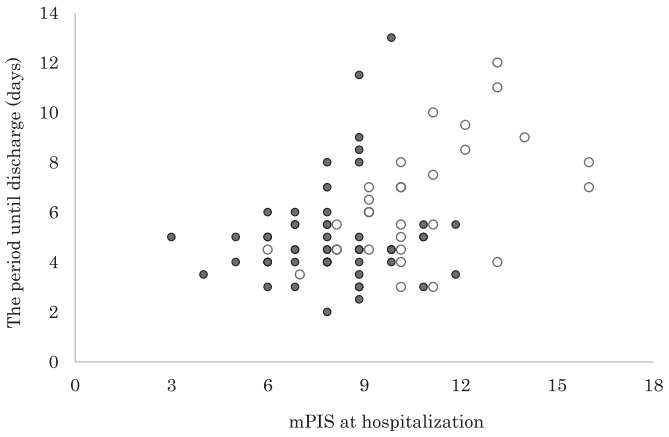

Fig. 4. Relationship between mPIS at hospitalization and the period until discharge. Open and closed circles indicate subjects with and without CIT, respectively. In all study subjects, a significant relationship was found ($r = 0.34$, $p < 0.01$). This was also the case when the relationship was examined in only subjects with CIT ($r = 0.53$, $p < 0.01$).

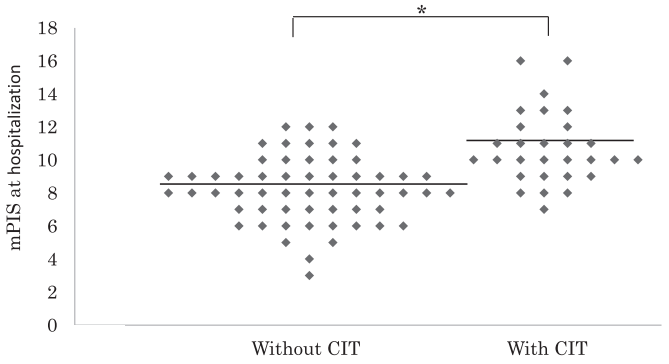

Fig. 5. Comparison of mPIS at hospitalization between subjects with and without CIT. mPIS was significantly higher in subjects with CIT (12.0 ± 0.5) than in those without CIT (9.3 ± 0.2). $^{*}p < 0.001$. CIT, Continuous inhalation therapy with isoproterenol.

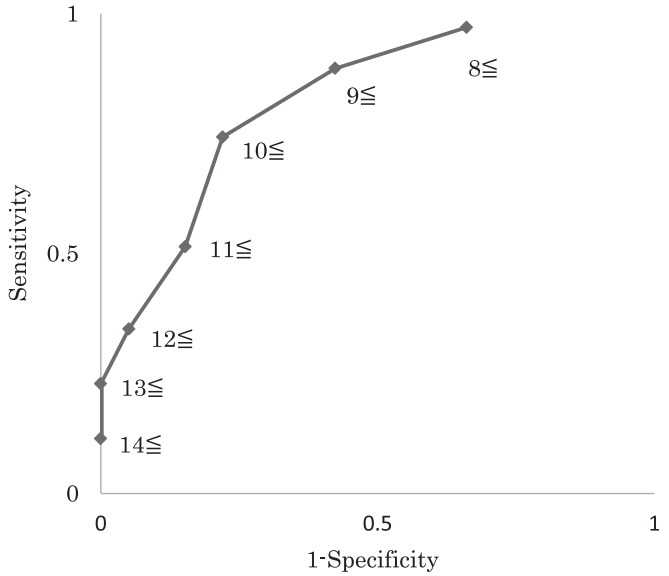

Fig. 6. ROC curve analysis for determining the indication of CIT using mPIS at hospitalization. A score of 10 was the optimal cutoff from perspectives of both sensitivity and specificity (74% and 78%, respectively).

ones, might help in determining whether to use CIT for acute exacerbation of asthma.

In the present study, there was a significant correlation between mPIS at hospitalization and hospitalization period, suggesting that mPIS was useful for predicting the clinical course after hospitalization. However, the correlation coefficient was not so high. Regarding the reason, it was possible that some patients whose symptoms exacerbated after hospitalization showed a lowered coefficient. It was also likely that hospitalization period had been partly affected by several reasons such as the convenience of the patient's guardians. The results of the present study were obtained via a retrospective method. Thus, a prospective protocol would further clarify the usefulness of mPIS as a predictor for hospitalization period.

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Conflict of interest

The authors have no conflict of interest to declare

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